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RECEIVER TECHNIQUES AND DETECTORS FOR USE AT MILLIMETER AND SUBMILLIMETER WAVELENGTHS

(Semi-Annual Report)

1 September 1964 - 28 February 1965

Grant Number NsG-74-60

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THE OHIO STATE UNIVERSITY
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REPORT 1093-26

REPORT
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THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION
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Sponsor	National Aeronautics and Space Administration Office of Grants and Research Contracts Washington, D.C. 20546
Grant Number	NsG-74-60
Investigation of	Receiver Techniques and Detectors for Use at Millimeter and Submillimeter Wavelengths
Subject of Report	Semi-Annual Report 1 September 1964 - 28 February 1965
Submitted by	Antenna Laboratory Department of Electrical Engineering
Date	28 February 1965

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SEMI-ANNUAL REPORT
1 September 1964 - 28 February 1965

I. INTRODUCTION

The purpose of this research program is to investigate various generation, measurement, detection, and receiver techniques, both conventional and non-conventional, in the millimeter and submillimeter wavelength regions. This report summarizes the results obtained during the grant period from 1 September 1964 to 28 February 1965, and those expected to be obtained by 30 September 1965. It then outlines briefly some activities which would form a logical continuation of this research, for the period from 1 October 1965 to 30 September 1966.

II. RESEARCH RESULTS FROM 1 SEPTEMBER 1964 TO 28 FEBRUARY 1965

During this period, we have completed the evaluation of the radiometer developed under this grant both theoretically and in the laboratory. The results obtained include a new theoretical analysis of the radiometer from the mathematical integral equation point of view, and the collection of a complete set of experimental data and its analysis in both the periodic and the aperiodic modes. These results have been published as the dissertation of Richard A. Williams. They indicate that the radiometer performs as expected and will be an extremely useful instrument. In the meantime negotiations have been completed for the use of this radiometer to observe solar radiation at Kitt Peak National Observatory, Tucson, Arizona, beginning March 24, 1965. Construction of a new high-temperature source (2500°K) using a high-current density carbon cavity, the design of an optical system for the 50-foot White absorption cell, and the construction of vacuum chambers for the radiometer have also been completed to enable measurement of water-vapor absorption in a controlled laboratory environment soon after the Kitt Peak Observation of the Sun. Figures 1 and 2 show the schematic diagram and the photograph of this black body source. Figure 3 shows the schematic diagram of the optical system for the water-vapor-absorption measurement in the 50-foot white absorption cell. Simultaneously,

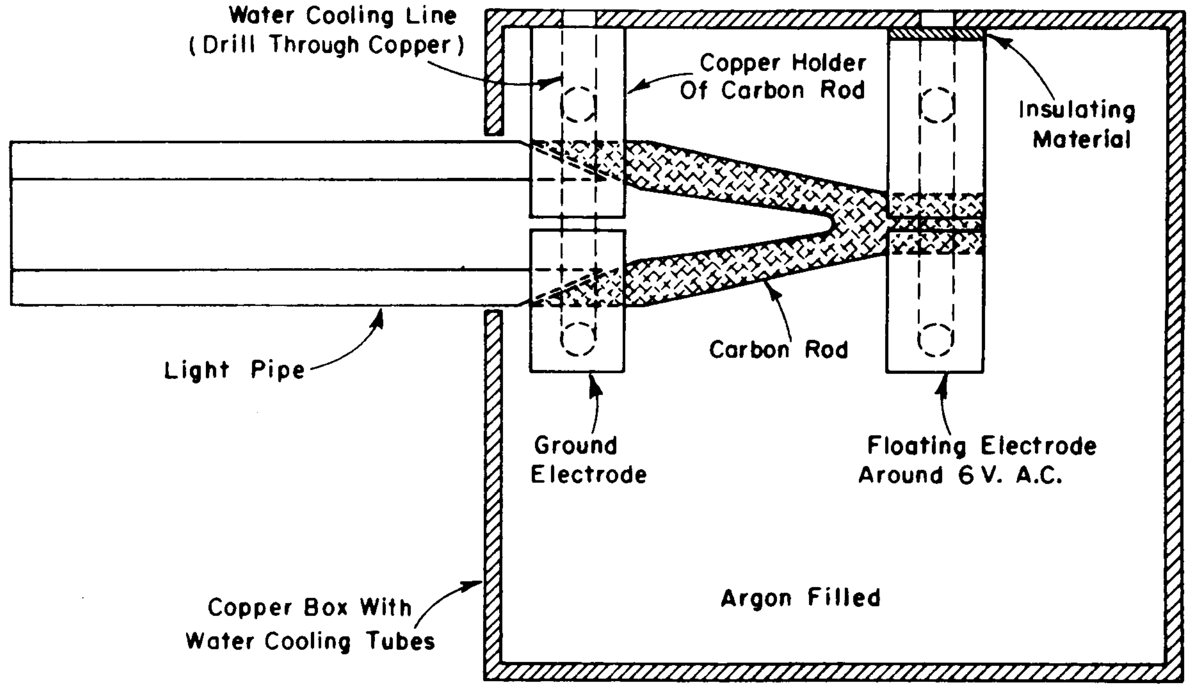

Fig. 1. Schematic diagram of the high temperature black-body source (rated at 550 amperes, 6 volts, 2500°K).

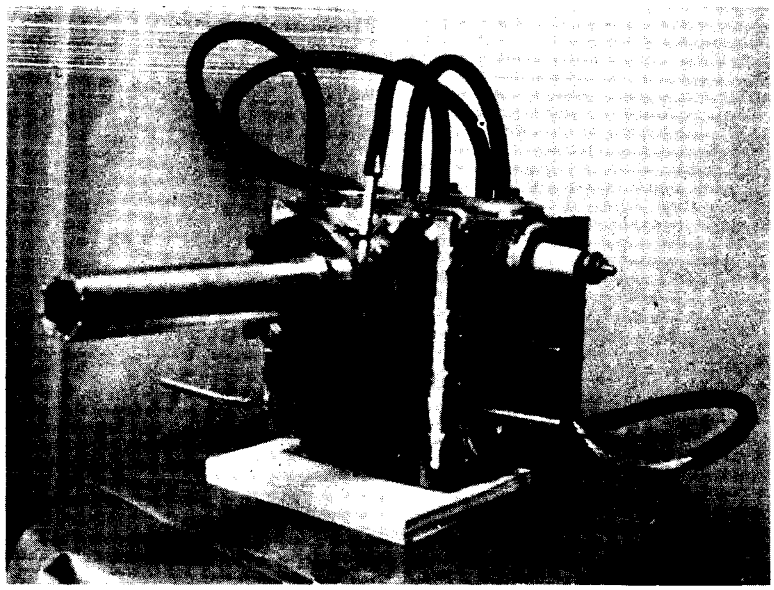

Fig. 2. Photograph of the high temperature block body source.

the construction of a 5-meter submillimeter helium-neon laser has almost been completed. We anticipate that neon-laser oscillation at 133 microns will be attempted very soon.

Figure 4 shows the schematic diagram of the submillimeter laser and Fig. 5 is a photograph of the laser.

III. RESEARCH PLANS FROM 1 MARCH 1965 TO 30 SEPTEMBER 1965

Clearly, the most interesting new results that will be obtained during this coming period would be the solar observation to be carried out with the 24-inch heliostat at the Kitt Peak National Observatory. This observation should give us some idea about: (a) the depth of the atmosphere as observed from 50μ to 1 mm in wavelength; and (b) any irregularities in the solar radiation as seen from the earth's surface. Besides the study about the atmospheric absorption this observation might also reveal some spectral characteristics of the solar radiation

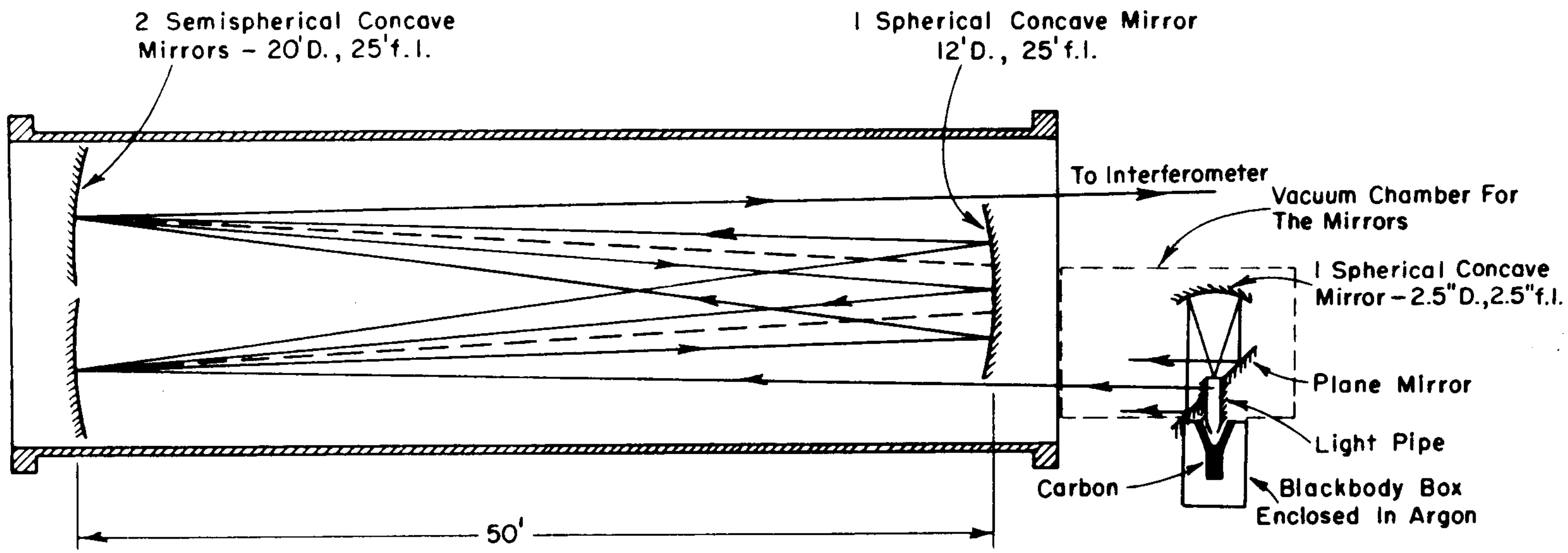

Fig. 3. Schematic diagram of the optical arrangement for the water vapor absorption measurement in the 50-foot White absorption cell.

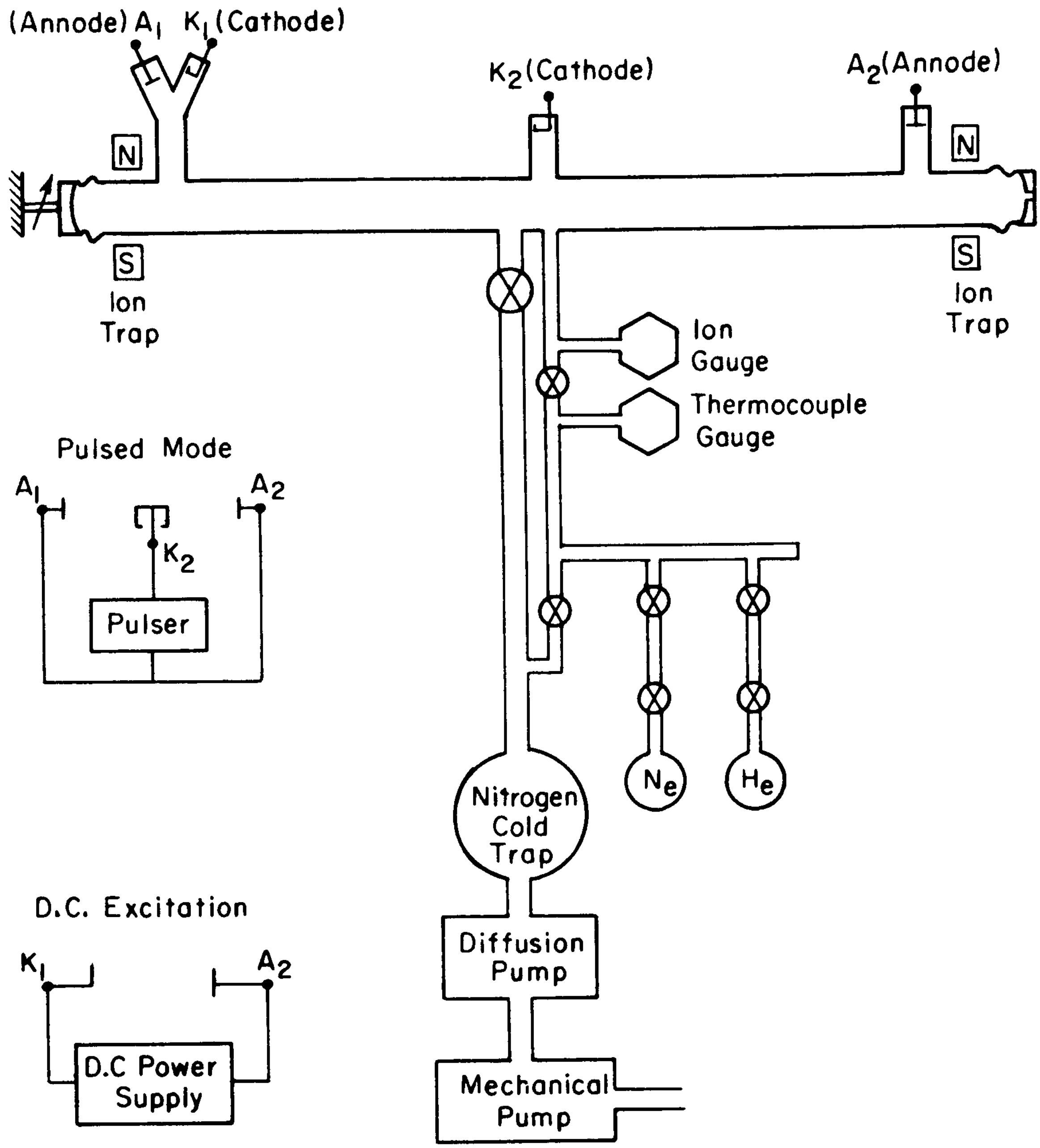

Fig. 4. Schematic diagram of the submillimeter gas laser.

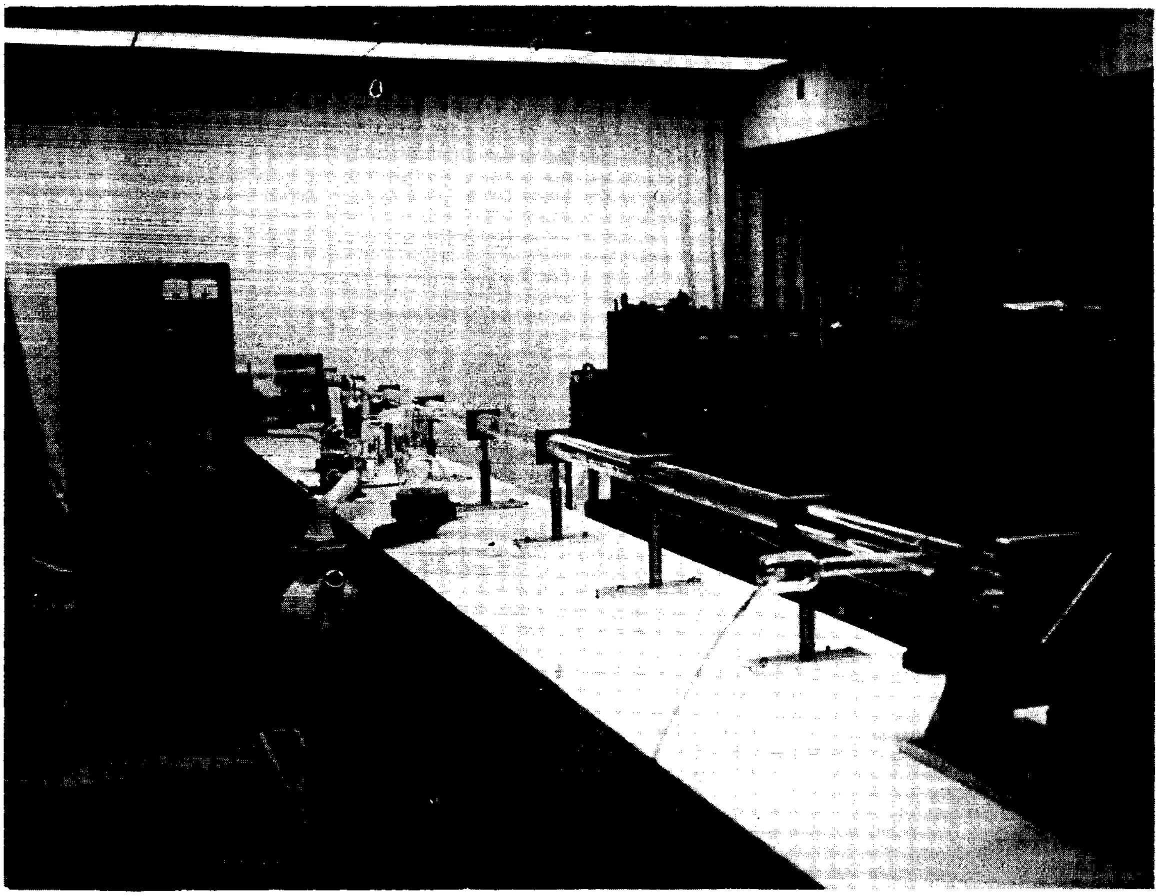

Fig. 5. Photograph of the 5-meter submillimeter gas laser.

itself. The merits of making extra-terrestrial astronomical observations at submillimeter wavelength is given in the Appendix. As soon as this initial solar observation is completed, the radiometer will be used in conjunction with the 50-foot White absorption cell at The Ohio State University to obtain the preliminary measurement in the water-vapor-absorption line position and line width as a function of pressure. These preliminary data plus those obtained from Kitt Peak should give us a rough estimate of the effective depth of the earth's atmosphere at submillimeter wavelengths, although detailed measurement of water-vapor-absorption will require a much longer period to accomplish.

Simultaneously, it is hoped that submillimeter laser oscillations will be observed during this period both on the cw and the pulsed basis at the known wavelengths. As soon as these laser oscillations are achieved, plans for studying the device characteristics of the gas laser, both as an amplifier and as an oscillator, will begin. The laser oscillator will be further used immediately as a discrete frequency source to examine the radiometer characteristics predicted and analyzed earlier.

IV. RESEARCH PLANS FROM 1 OCTOBER 1965 TO 30 SEPTEMBER 1966

Assuming the submillimeter laser oscillation has been achieved before 1 October 1965, we propose that the device characteristics of these lasers be studied in the next grant period as follows:

a) Investigation of the laser oscillator characteristics as a function of cavity configuration and discharge conditions (i.e., cw or pulsed). Presumably by varying the cavity configuration one may obtain either new laser oscillating transitions of larger power output and different mode structures in existing laser transitions.

b) Investigation of the laser as a submillimeter amplifier from both the gain-bandwidth point of view and the noise analysis point of view.

Besides studying the laser characteristics, we also propose that the laser be used as a source to measure the refractive index and the opaqueness of materials at the submillimeter wavelength.

On the other hand, we propose that the water-vapor-absorption studies be continued in this period so that detailed experimental data on line strength, line width, and line positions be obtained including the use of lasers as sources together with a theoretical analysis in such a way that the transmission of submillimeter waves through the atmosphere can be predicted.

By the end of this period we should have a submillimeter oscillator and possibly a submillimeter amplifier in addition to the interferometric receiver. These can be used in a variety of future experiments; as for example, mixing, harmonic generation, and material studies.

The interferometric receiver, the high-temperature carbon source, and the 50-foot absorption cells could also be used to measure the transmission of submillimeter-wavelength radiation through various simulated planetary atmospheres such as carbon dioxide, methane, nitrogen, etc., or any desired mixture of these gases at a wide range of pressures.

V. PUBLICATIONS

1. R.A. Williams and W.S.C. Chang, "Interferometric Wavelength Selection for Submillimeter Radiometry," Preceedings of the Symposium on Quasi-Optics, Polytechnic Institute of Brooklyn, p. 607, 1964.

2. Glen G. Shephard, "Static Response Characteristics for a Carbon Bolometer," to be published in Journal of Applied Physics, 1965.

3. W.S.C. Chang, J.G. Meadors, N.R. Kilcoyne, and J.T. Mayhan, "On the Properties of Partially Coherent Light," presented at Laser Symposium, Electrochemical Society, San Francisco, California, May, 1965.

APPENDIX

Observations of the sky have traditionally been made at visible-light wavelengths, and at centimeter and near-infrared wavelengths. These observations have resulted in data which has led to a better understanding of the formation of the universe, and have also yielded information which is of particular importance to the intended interplanetary space flights. One missing link in these observations is the study of the sky in the millimeter-submillimeter wavelength regions, say from 50 microns to 1 millimeter wavelength.

In the past, submillimeter-wavelength observations have not been possible because of the lack of instrumentation. However, with the advent of more sensitive detectors[1,2] and with the development of the interferometric wavelength-selection mechanism[3], it is now possible to make direct observations at these wavelengths with reasonable spatial and frequency resolution. Furthermore, the possibility of performing astronomical observations from balloon-borne or satellite-borne platforms also minimizes the transmission loss caused by atmospheric water-vapor absorption. The merits of making such observations can be listed as follows:

(1). <u>From the scientific point of view</u>: It has been well known in the past that the signal received from many of the stellar and interstellar sources in the radio-frequency region is much larger than that which would be expected from a black-body-radiator model of these sources. The data which could be obtained in the far-infrared and submillimeter-wavelength regions would provide additional information on the deviation from the black-body radiation model, which in turn may aid in the identification of the possible mechanisms of these non-thermal radiations. For example, the non-thermal part of the cosmic radiation at radio frequencies has been ascribed to the synchrotron radiation of fast electrons in magnetic fields, and some of these electrons may be produced through meson production in cosmic-ray particle collisions with matter in the galaxy and beyond. The determination of this millimeter and submillimeter radiation will fill a large gap in our present knowledge. Correlation of submillimeter-wavelength observations of solar flares with observations at other wavelengths (radio and optical) should also yield very interesting data on the origin of the submillimeter radiation and the nature of the solar flares, and may be of some value in the prediction of these flares. The possibility of obtaining high spatial resolution with moderate-sized antennas (due to the short wavelengths involved) should also prove to be convenient both in the detailed examination of the sun's surface, and in the more accurate determination of the temperatures of other planetary objects such as Venus, Mercury, etc. in the submillimeter region. Such measurements are also likely to be very useful in verifying models of the atmospheric composition and structures of these bodies.

(2). From the space-exploration point of view: Recently, systems for reconnaissance, detection, ranging and communication in the far-infrared and submillimeter regions have been proposed for operation from satellite platforms orbiting high above the attenuating layers of the atmosphere. Here the system designer, free from the adverse effects of atmospheric attenuation, must recognize a new type of background environment (i.e., radiation noise from sources in space rather than from atmospheric sources) in which the system must operate, and which may well determine the practical limits of its performance. Therefore, a mapping of the radiation noise at wavelengths from 50 microns to 1000 microns may very well provide us with an estimation of the effectiveness of using submillimeter radiation for communication and exploration applications. Also, if the measurement of solar submillimeter-wavelength radiation could aid in the understanding of solar flares a contribution to the safety of future manned space flights might be made, since such flares are the source of particle radiation damaging to both men and equipment.

(3). From the speculative point of view: Finally, from the speculative point of view, the fact that submillimeter astronomical observations have not been made up till now is a very important factor itself in pointing out the importance of making such observations. Within the large wavelength region from 50 microns to 1000 microns there may possibly be new interactions and radiation mechanisms. Astronomical observations in this frequency range will either lead to new discoveries or to the confirmation of existing theories. After all, Columbus never knew the existence of America before his adventure!

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1. Low, F. J., "Low Temperature Germanium Bolometer," J. O. S. A., Vol. 51, (1961) p. 1300.

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